Capacity Planning
for the
Future Space Mission Environment

Dwight P. Holmes

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, ColiJornia91109
(818)-354-6224 voice / (818) 393-1692 fax
dwight.p. holmes@jpl. nasa.gov

Introduction

This paper intends to describe a part of the story of NASA's support of deep space robotic missions using the worldwide collection of antennas and equipment, known as the Deep Space Network, (DSN). There are numerous aspects involved in the support of a deep space mission, all of which must happen successfully, in order for the mission to be successful. Not the least of which, is the ability to communicate, and the utilization of the capabilities that the communications system provides. (The ability to send data to, and control the spacecraft, ***Command***. The abi 1 it y to col lect data from the spacecraft, ***Telemetry.*** And finally, the ability to use the communications system as a tool for knowledge of the position, velocity, and acceleration of the spacecraft, ***Tracking***.)

By now everyone is aware of the outstanding success of the Mars Pathfinder mission. The success of Pathfinder depended, in large measure, on detailed advance planning. Much in the way a successful mission develops its plans from launch through detailed real time operations, the Deep Space Network develops detailed plans and schedules for the success of the aggregate set of NASA and non-NASA missions. The network must provide the resources to insure that each mission can meet its scientific and operational objectives. At the same time, the network must plan to maximize the utilization of its assets, and build capability and capacity improvements for the future.

This paper is intended to provide some insight into the evolution of the DSN planning and the future mission set which drives that evolution. Hopefully, this paper will also clearly describe the methodology behind capacity planning, as well as the use of the tools and processes for DSN resource allocation.

Background

A process that recognizes that the Deep Space Network is a limited resource has been in place for the more than a decade. [1] The process attempts to maximize the utilization of the network while optimizing the collective science return of the mission set. Unlike Earth orbiters, deep space missions tend to have relatively long tracking passes and be driven by unique science collection events. A resource allocation process is required so that these unique science events can be captured with minimal impact to other missions, and visa versa. The big science missions of the past 20+ years were infrequent enough so that allocating resources was never a real issue. The challenge was to protect smaller science missions. The bigger missions would generally have the budget and the priority. Enter the era of "Faster, Better, Cheaper". Missions are proposed and launched on much faster time tables with budgets an order of magnitude less than their ancestors. Proposal to launch can be three years, at a budget of a few hundred million, instead of seven to ten "years at several billion. While more frequent missions may usher in a potential renaissance for science, no one mission carries the "big stick". Many missions will be competing for the limited resources of the Deep Space Network with potentially competing science objectives, milestones and time tables.

In an age of reduced budgets, the ground network resources can not be squandered. It is imperative to plan smarter by looking at the whole picture, the space component as well as the ground component. In an effort to provide the necessary space communications resources, smart planning must start at the initial design of a mission. The **DSN** can no longer afford track "dumb" spacecraft. Complete mission planning includes the space and ground segment, each trade-off must integrate Command, Telemetry and Tracking into the whole space/ ground system for the lowest overall cost and best performance. Spacecraft requirements translate to ground requirements for the entire mission set.

The challenge at hand is to be able to evaluate the capacity and capability of the ground segment to support the aggregate mission set. In order to meet the future challenge we must not only reevaluate how we use the resource we have, but must find ways to plan for the capacity of the future Deep Space Network. Capacity planning does not mean we simply add capacity to meet the challenge by building new antennas. That strategy does not fit within current budgetary guidelines. What it does mean, is that we evaluate the tools and process for understanding the true limits on that capacity. We design both the network and the missions in concert to meet the science objectives of the enterprise. It means looking at ways to incrementally increase capacity to meet mission need. It means the potential utilization of assets outside the traditional NASA networks. Finally, it requires the design and evaluation of strategies which meet the unique mission set criteria, and ensure that the network design is truly and end to end solution which includes the space segment as well as the ground segment.

The future mission set

The future mission set is surely a nebulous entity. The struggle for definition is basically due to the process imposed for budgeting space missions. Quite simply, unless a mission is approved, no one is willing to commit beyond the seed money for concept development. At that point, not enough of the design is in place. Without the design, the communications requirements can not be defined. As has happened all to frequently, the communications requirements arc developed late in the design process. The evolution of the future mission set owes its existence to the concept of Faster, Better, Cheaper. Without some knowledge of the future mission set, lead times for planning of additional network capacity can not match the shortened concept to launch cycle of the newer missions.

The future mission set for the Deep Space Network is organized in accordance with major "scientific program thrusts and along NASA enterprise lines. Therefore, the future mission set includes missions from the Discovery Program, Outer Solar Sytem Program, New Millennium Program, and the Integrated Mars Program. Cooperative missions with non-NASA entities are included in the future mission set. Sun-Earth connection and Earth observing programs are included when such programs require high a Earth orbit profile supportable by other NASA ground resources.

The current approved mission set tracked by the Deep Space Network, consists of 28 simultaneous missions in 1998 with a total of 13 on the planning horizon. The profile of the future mission set adds 55 new missions through 2022, peaking at 37 simultaneous missions in **2006.** When viewed in total, the future mission set increases the overall mission load by an additional one third in 2007. However, that is not the whole story. The future mission set being studied at JPL is a conservative set with the reasonable assumption that these missions will likely happen. A more aggressive proposal by NASA Administrator Dan Goldin, assumes a future launch rate on the order of one per month. This results in a peak of 78 simultaneously tracked missions by the year 2007.

It is clear that in the faster, better, cheaper paradigm, missions whose budgets are an order of magnitude less than a decade ago, on shortened design to launch cycles, will drive the NASA's resources like no other endeavor.

Table 1: Program Future Mission Composition

Integrated Mars Missions	13
Cooperative Missions	12
Discovery Missions	11
Outer Solar System Missions	10
New Millennium Missions	7
High Earth Orbiters	2

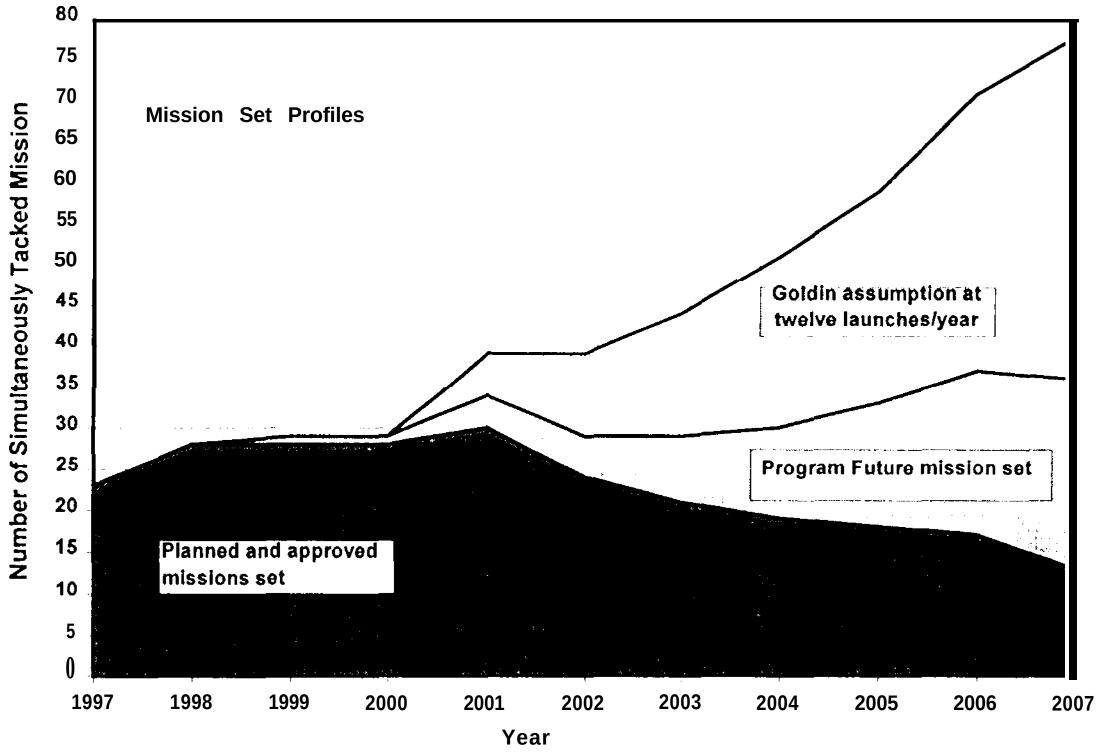

Figure 1

Graphic of Figure 1 defines the future mission set with Dan Goldin's assumptions. If an average mission life of five years is presumed, three years prime, two years extended, a steady state of between **50** and **60** simultaneous missions per year would result. The DSN is currently at 15°/0 overload at 28 simultaneous missions. A doubling of the potential load on the DSN requires much smarter capacity planning. For example, a Beacon mode approach assumes the network could conceivably cut the contact time in half. [2] Other potential solutions, although not significant individually, could, in combination allow, NASA to approach doubling the size of its mission set.

An average mission set of 50 to 60 simultaneous missions is a reasonable assumption at twelve launches a year. In practicality, that level would most likely be reached at something less than twelve launches per year. Some missions will be active longer than others. However, the scientific propensity is to gather as much data as possible and operate the mission as long as possible to maximize the return on investment, intellectually, as well as economically.

Available network assets:

"l'he Deep Space Network is an international network of antennas that supports both interplanetary spacecraft and high Earth orbiter missions. 'l'he unique capabilities of the network also allow it to be used for direct scientific investigation of the solar system and the universe utilizing solar system radar and radio astronomy.

The DSN currently consists of three deep-space communications complexes placed approximately 120 degrees apart around the world: at Goldstone, in California's Mojave desert; near Madrid, Spain; and near Canberra, Australia. The strategic placement of these complexes permits constant observation of spacecraft as the Earth rotates.

All DSN antennas are steerable, high-gain, parabolic reflector antennas operating in the microwave bands. Figure 2 is a simplified chart of antenna sizes, operating frequency, capability, and location.

ANTENNA	FREQUENCY			LOCATION		
	S-BAND 2 GHz	X-BAND 8 GHz	KA -BAND 32 GHz	Canberra Australia	Madrid Spain	Goldstone California
70 Meter	▼▲	▼▲		x	x	x
34 Meter High Efficiency	▼	▼▲		x	x	x
34 Meter Beam Waveguuide Subnet 1	▼▲	▼▲		x	x	x
34 Meter Beam Waveguuide Subnet 2		▼▲	▼▲			x
34 Meter Beam Waveguide High Speed	▼▲					x
26 Meter	▼▲			x	x	x

Figure 2

The assets and capabilities of the Deep Space Network are in the midst of an evolution. **New 34** meter beam waveguide antennas are being constructed at all sites. By the end of 1998, the 34meter beam waveguide antennas will have their full complement of frequencies for both transmit and receive. By the middle of 2001 all of the large 70 meter antennas will have X band transmit capability. Additional capability at the Goldstone complex will include full transmit and receive capability at Ka band. This capability is currently experimental but could become a fully operational frequency throughout the network of the future. Ka band has the potential of significantly improving G/T performance of the 34 meter beam waveguide subnet with the end result being greater telemetry throughput for a shorter tracking pass.

Future Mission Planning

The planning process starts with the requirements of an individual mission. Each mission, or project, submits its requirements for communications services based on the unique needs of the mission. Those needs, which may be in conflict with other missions being supported by the Deep Space Network, must be negotiated to and agreed upon by both parties. l'he service requester and the service provider. The aspect of early negotiation with the mission or project is a fundamental aspect of the planning process. 'l'he reasoning is fairly straight forward. The Deep Space Network is a limited resource. The number antennas are fixed, and the budget for new antennas is severely limited. The other part of the limitation, is that deep space missions pose a unique problem. Access, or view period, which is a measure of the spacecraft time in view, is geometrically driven by the dynamics of the Earth's rotation and orbit around the sun, and the spacecraft trajectory. For deep space missions that are relatively close to the Earth, the spacecraft trajectory is much more of an issue. However, at several A. U., the spacecraft remains relatively fixed in the sky compared to the motion of the Earth. This is clearly not the case for Earth orbiting missions. Earth orbiters, and in particular, low Earth orbiters, tend to have frequent short passes. Their advantage is that there is usually more than one opportunist y to establish a downlink and dump the spacecraft's data contents. From a "'statistical point of view, a constellation of low Earth obiters would present a set of tracking opportunities at any one tracking site that looks stochastic. [3] in fact, algorithms that model low Earth orbiter opportunities for any long range planning are statistical. Low Earth orbiter parameters are short lived due to the nature of the variation and complexity of forces that perturb the orbit. As a consequence, long range planning and scheduling beyond a few weeks is not practical for low Earth orbiters.

High Earth orbiters, have some of the characteristics of both deep space missions and Earth orbiting missions. The pass lengths can be relatively long, particularly for highly elliptical orbits. The orbits, and therefore the view periods, at a tracking site are generally more deterministic. At high spacecraft altitudes, atmospheric drag force components are reduced and the Earth's gravity field begins to look more like a point source vs the detailed spatial field distribution near the Earth. NASA's Deep Space Network tracks both high Earth orbiters and deep space missions. The challenge is to provide the long range resource planning and capacity analysis for the full mission set, when in fact, trajectory models for high Earth orbiters and deep space missions are not fully compatible.

Methodology and tools for Future Mission Planning:

As was mentioned in the background section, resource allocation was and is predominantly concerned with allocating the resources of the Deep Space Network among the "baseline" mission set. The baseline mission set represents the currently approved and on orbit and "ready to be launched" missions. 'l'he baseline mission set also has the benefit of a fairly complete requirements set. In order to perform an allocation, the trajectory, and ultimately the view period with respect to the tracking station, as well as the number and timing of the tracking passes are required. Resource allocation takes the sum of all known requirements and with the judicious use of an event/phase based priority scheme can generate set of loading profiles which identify the allocatable tracking hours out of the hours requested for each mission by each network asset. By noting allocated assets by mission and the view periods for each mission, a contention profile can be developed. The contention file identifies conflicts among missions for resources. The contention profile is the primary tool for negotiating requested time between competing projects vying for the same resource. The resource allocation process requires significant interaction between project representatives and the resource allocation team. It operates on a near continuous basis and is the genesis for the detailed schedule used for real time operations by Deep Space Network.

A suite of tools is used to analyze the contention among missions and identify potential allocation possibilities. The tool suite, includes the PC4CAST forecaster, a viewperiod viewer, an event editor, and a user loading profile. Each forecast is week based, run for a single year, with the data set is entirely self contained. Figure 3 is an example of a user loading profile. The profile includes all the elements required to run a forecast; view period ID, user name, network resources, track duration, and the number of tracks per week. Output data is available in both a weekly and a monthly format. The week based algorithms provide an easy way to record and account for mission requirements, but do not allow sufficient detail to define single events within a week.

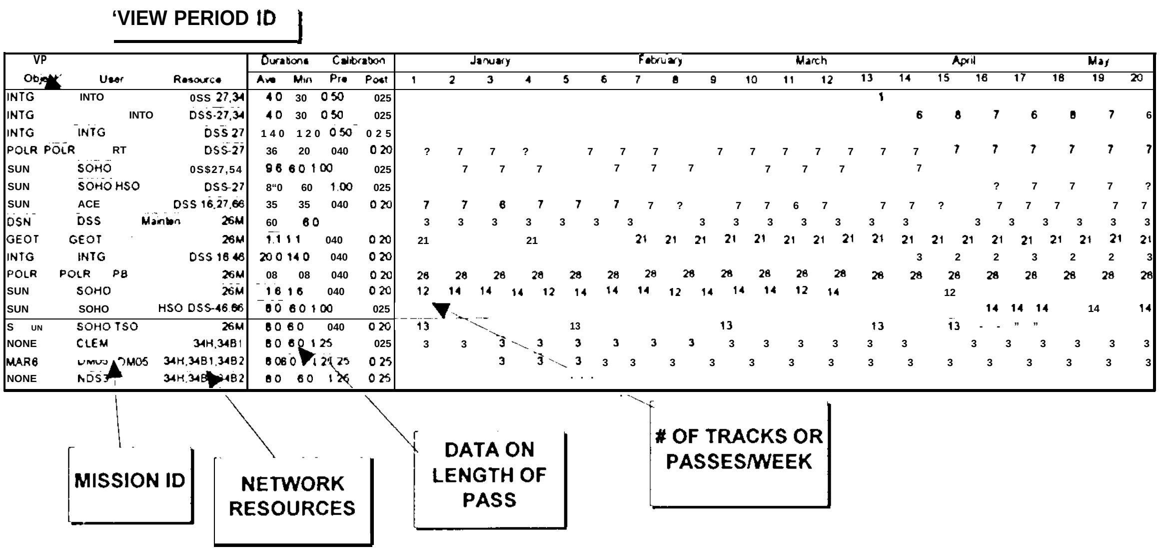

Figure 3

With proper use of the tool suite, a significant amount of information can be acquired, such as asset utilization, user load distribution, and expected usage profiles. For resource allocation, long range planning and capacity projection, these tools have been very adequate.

The methodology required for truly advanced planning requires analysis with significantly less information. The farther out the launch date, the less detailed knowledge available. Analysis of the future mission set demands capabilities beyond those are currently available within the forecasting tool suite. The future mission set contains missions in varying states of design. From simple, "Announcement of Opportunity" placeholders, to quasi detailed Outer planet missions. The future mission set has one other attribute which that makes it difficult to analyze. The future missions don't start at a particular date in the future after which all other supported missions cease to exist. The current planning mission set will coexist with proposed future missions. The analysis time frame extends over a span of time in which currently active missions with detailed knowledge coexists with the less defined future missions.

In defining a methodology for analyzing the future mission set, one of the primary drivers is to allow mission requirements to be part of a database, independent of the forecasting engine. The objective is to provide scenarios for future missions that are independent of the baseline mission set. Future mission set data that must be modeled because of limited requirements knowledge, needs to be evaluated against a baseline set with mature requirements.

The solution to the analysis problem requires the ability to separate components of the analysis. A broadly designed database separate from the analysis engine provides the necessary enabling functionality for analyzing the future mission set, while maintaining the configuration control over the current planning set. "l'he database that is the repository of all the mission information including event/phase driven requirements and all of the data pertaining to the availability, and capability of the Deep Space Network is the Mission and Asset Database. The database integrates all of the elements required for a complete forecast and capacity analysis, and is depicted in Figure 4.

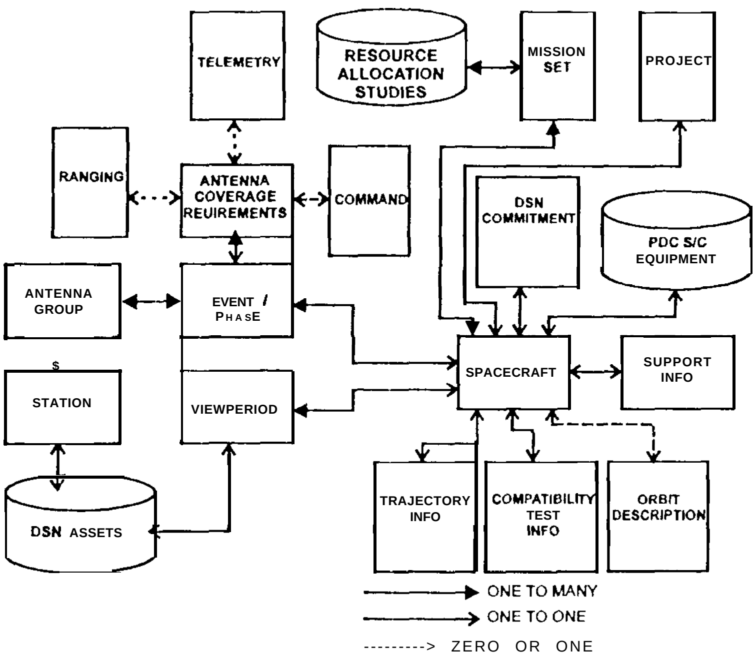

Figure 4

MISS1ON AND ASSET DATABASE DESIGN

Separate from the database, is an engine which combines the functions of the previous tool suite, into single integrated application. The functionality of the application includes advance modeling through scheduling and has the capability to allow incremental buildup of a mission set with alternative requirements and multiple scenarios. In particular, the future set is a scenario of the baseline planning set. The planning set is maintained under configuration management control by the Resource Allocation Team, while the future mission set is purely speculative and may undergo significant changes. The future mission set may contain multiple trajectories and multiple targets depending on various approval and/or proposal acceptance possibilities. One may also wish to develop scenarios in which certain asset capability is available within the Deep Space Network. All of these methodologies are available with TIGRAS. TIGRAS is the TMOD[1] Integrated Ground Resource Allocation System.

Conclusion

Current work is focused on developing scenarios for the future mission set and providing the data as input to the database. The scenario models include multiple future mission sets with alternative campaign objectives, trajectories, potential trade space models, and an advance ground network for improved data return and reliability.

A complete analysis with all scenarios using the advanced tool, TIGRAS, has yet to be completed. Preliminary analysis based on the phased based requirements of the future mission set have demonstrated that current future mission set plans do indeed exceed the current Deep Space Network capability. The magnitude of the contention, and the trade space available based on estimated requested hours of support remains for detailed analysis.

Without the tools, and the ability to project beyond a few years, the evolution of the Deep Space Network will be driven by near term mission goals. With a truly long term projection, the network can provide capacity for new missions consistent with evolving mission technology, integrated network capability.

1. Note; TMOD is the acronym for the program management office of the Deep Space Network, Telecommunications and Mission Operations Directorate.

Acknowledgments

The work described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of I'ethnology under a contract with the National Aeronautics and Space Administration.

The author would like to thank Gene Burke for his guidance and encouragement; Frank Leppla, Dave Morris, and Mark Brewer of the Resource Allocation Team for their patience and encouragement during my training period; and their forgiveness when I would break the software. In particular I would like to thank Chet Borden, Sil Zendejas, and Yeou-Fang Wang for their genius in the design and implementation of the database and tools. Finally, I wish to thank J. R. Hall for his inspiration and initially thrusting me down this path.

References

[1] S. J. Loyola, " PC4CAST - A Tool for DSN Load Forecasting and Capacity Planning," *The Telecommunications and Data Acquisition Progress Report 42-114*, August 15, 1993, Jet Propulsion Laboratory, California Institute of "1'ethnology, Pasadena, California

[2] D. Sweetnam and H. Hotz, " Spacecraft Demand Access: Autonomy for Low-Cost Planetary Operations," *The 2nd International Symposium on Reducing the Costs of Spacecraft Ground Systems and Operations*, July 23, 1997, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

[3] G. Fox and C. Borden, "Low-Earth-Orbiter Resource Allocation and Capacity planning for the DSN Using LEO4CAST," *The Telecommunications and Data Acquisition Progress Report 42-116'*, August 15, 1994, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

[4] Telecommunications and Mission Operations Directorate ('I'MOI)), "JPL Deep Space Network Long-Range Resource Allocation and Capacity Projection Plan for January 1998- December 2007," *JPL D-14054*, November 1996, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California